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SOLAR GASIFICATION OF CHARCOAL, WOOD AND PAPER

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Resume

Charbon de bois, de bois, et papier ont été gazeifiée dans un four solaire de 2 kW, par injection directe d'eau sur le combustible. Dans le cas du charbon, environ 30% de l'énergie solaire incidente a pu être stockée, et 55% de l'eau injectée a été consommée. On peut expliquer les resultats obtenus avec le bois et le papier par une pyrolyse suivie de la gazeification du charbou formé.

Abstract

Charcoal, wood and paper have been gasified in a 2 kW solar furnace by injecting water directly on the hot fuel. In the case of charcoal, approximately 30% of the incident solar energy was stored as chemical energy and 55% of the injected water was consumed. Wood and paper gasification can be explained by conventional pyrolysis followed by the gasification of the charcoal formed.

Introduction

When steam contacts solar-heated carbonaceous materials, gasification occurs, producing mostly H_2 and CO. The process results in the storage of solar energy because the fuel value of products is greater than the fuel value of the materials gasified to produce them. In addition, H_2 and CO are basic materials in the organic chemical industry. Presented here are our results on the gasification of coconut charcoal, wood and slick-surfaced magazine paper.

The packed-bed reactor shown in Fig. 1 was positioned at the focus of a vertical-beam 2 kW solar furnace. Highest reaction rates were measured when the diameter of the solar beam was equal to the diameter of the bed. The solar power on the bed surface was determined by a flowing-water calorimeter. Placing a reactor window in front of the calorimeter decreased the power by 9.2%. As the bed was consumed by gasification, it was pushed toward the focus by means of the hand-operated piston as shown. The product gas was passed through a water trap, filter, and gas-flow meter. Gas composition was determined by chromatography.

A fluidized-bed reactor was also used for charcoal gasification. As described by Flamant (2), this reactor was a silica-glass tube 3.4 cm in diameter and 19.5 cm high. The tube was positioned vertically in a 2 kW solar furnace so that the focus was on the upper surface of the bed before fluidization.

Fluidization and gasification were achieved at the same time by the upward flow of CO_2 gas through the bed. A white ceramic ring was put outside the glass tube below the focus as an insulator and reflector.

The performance of these two reactors was compared on the basis of the amount of solar energy stored and the fraction of reactant gas consumed. The storage of solar energy can be determined from the fuel value (heat of combustion) of the product gas (ΔH_p), the heat of combustion of the fuel gasified (ΔH_F), and the solar energy (ΔH_s) used during gasification as follows:

$$\%\ \text{solar energy storage} = \left(\frac{\Delta H_p - \Delta H_F}{\Delta H_s}\right) 100$$

The amount of carbon gasified was determined in two ways; by the gas production and by the loss in weight of the bed. The agreement between the two methods was $\pm$ 5 g, and the total amount of carbon gasified was between 20 and 100 g.

Granular coconut charcoal was used for calibration experiments because it is nearly pure carbon (1.5 $\pm$ 0.5 wt %H) with a low ash content (1.2 wt%).

Comparison of Reactors Using Charcoal Gasification With CO_2

A comparison of the efficiency of solar-energy storage by the two reactors is shown in Fig. 2a.

The maximum storage efficiency using the fluidized bed reactor was about 10%, achieved by using a low CO_2 flow and small char grains (0.3 - 0.8 mm). The solar power was 1.1 kW. The bed temperature was 985°C. The glass tube was not damaged unless the CO_2 flow was reduced so that the bed temperature exceeded 1000°C.

We found the fraction of solar energy stored using the packed-bed reactor and CO_2 was 35 ± 5% independent of the solar flux over the range we investigated (27 - 64 watts/cm^2) - provided we kept the ratio solar power/CO_2 flow rate constant.

Char Gasification With Steam

Steam was generated by injecting water directly into the focus of the furnace within the packed-bed gasifier. The results (Fig. 2b) show a maximum solar energy storage of 32% when the rate of water injection was 6 mℓ/min g and a 50% utilization of steam. The average composition of the exit gas is shown in Table 1. The CO/CO_2 ratio was, in fact, a function of the water flow rate. It decreased from 6 at 4.5 mℓ/min to 2 at 10 mℓ/min. The volume of dry gas produced per gram of charcoal was 3.8 ℓ (at OC and 1 bar). A gas-production record is given in Fig. 3.

TABLE 1

Gas Composition and Yields
(Solar Gasification with Steam)

Fuel	Gas Composition H_2	CO	CO_2	CH_4	C_2H_4	Gas Heating Value KJ/Mol	Btu/scf	Ash %	Gas Yield M^3/Kg*
Charcoal (Coconut)	57	32	11	0.3	0.0	260	290	1.2	3.8
Wood (Pine)	57	29	8.3	4.4	0.75	300	340	~0.5	1.0
Paper (Magazine)	64	22	11	2.3	0.2	270	300	40	0.4

(* OC, 1 bar)

Gasification of Wood and Paper

Wood and paper have been gasified with steam under a solar flux of 60 $\pm$ 10 watts /cm^2. Two kinds of wood samples were prepared from the same piece of seasoned (air dried) pine.

1. Cylinders 4 cm in diameter and 10 cm long (density 0.60 g/cm^3)
2. Sawdust (bed density 0.20 g/cm^3)

As in the case of charcoal, the efficiency of gasification of wood is a function of the rate of water injection. The yield of gas was 1 $\pm$ 0.1 m^3/Kg (0°C 1 bar) for both the solid wood samples and the sawdust.

Pyrolysis of 1 Kg of most kinds of wood yields approximately 0.2 m^3 of gas and 200 grams of fixed carbon (charcoal) (2). We have determined that the steam gasification of 1 gram of charcoal yields 3.8 ℓ of gas, or 760 ℓ for 200 grams of charcoal. The total volume of gas we observed from the steam gasification of wood (1 m^3/Kg) corresponds to the sum of gas from pyrolysis (0.2 m^3) and the gas produced by the gasification of the residual or fixed charcoal (0.76 m^3).

Solar gasification of wood with steam increases the fuel value of the wood by approximately 20%. The average composition of the gas produced is shown in Table 1. Liquid hydrocarbons (tars) were also produced during wood and paper gasification, and they collected on the walls of the exit tubes. They were not analyzed.

The steam gasification of slick-surfaced magazine paper produced 75 ℓ of gas in 25 min from 191 grams of paper. The paper contained approximately 40% ash, and the gas yield was approximately 0.4 m^3/Kg as shown in Table 1. The sample was a tightly rolled magazine 4.6 cm in diameter and 16.5 cm high. The average composition of the gas produced is similar to that from wood, as shown in Table 1. The decreasing rate of gas production in the case of paper (Fig. 3) was due to liquid-ash build up.

Acknowledgments

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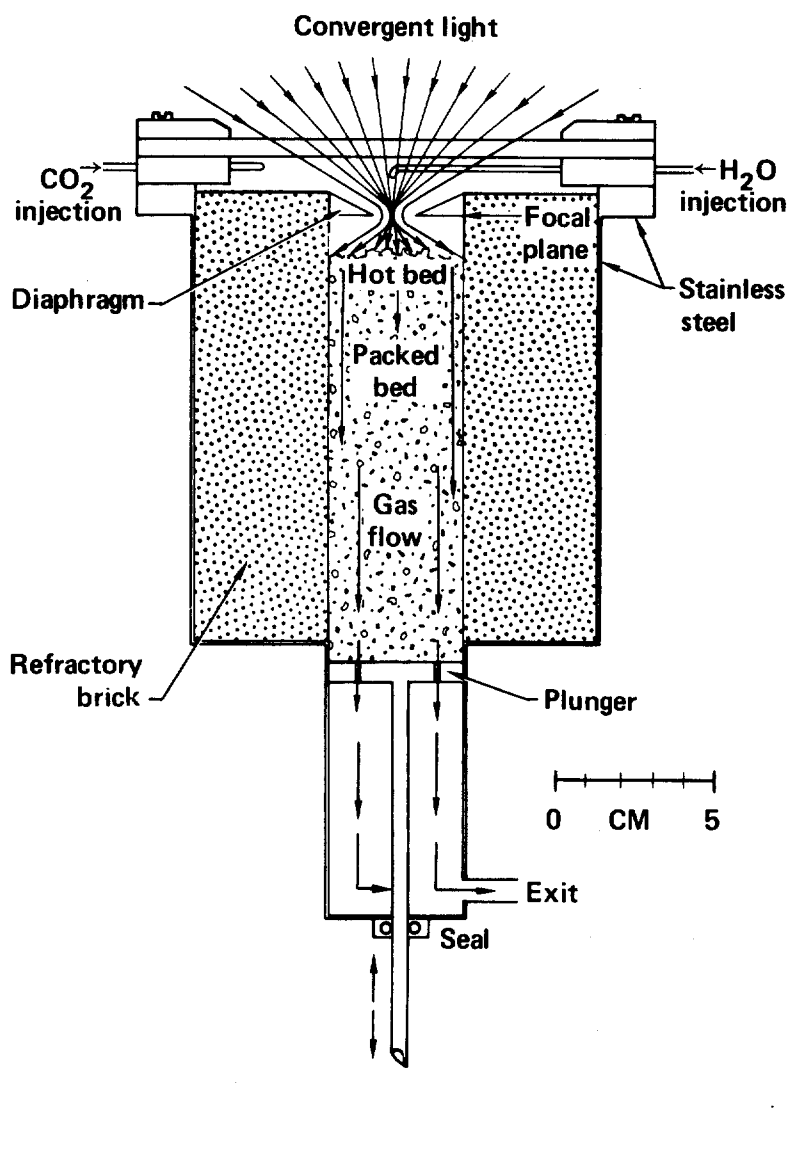
References

1. G. Flamant, and others, "Experimental Aspects of the Thermochemical Conversion of Solar Energy, Decarbonation of $CaCO_3$", J. of Solar Energy (In Press).

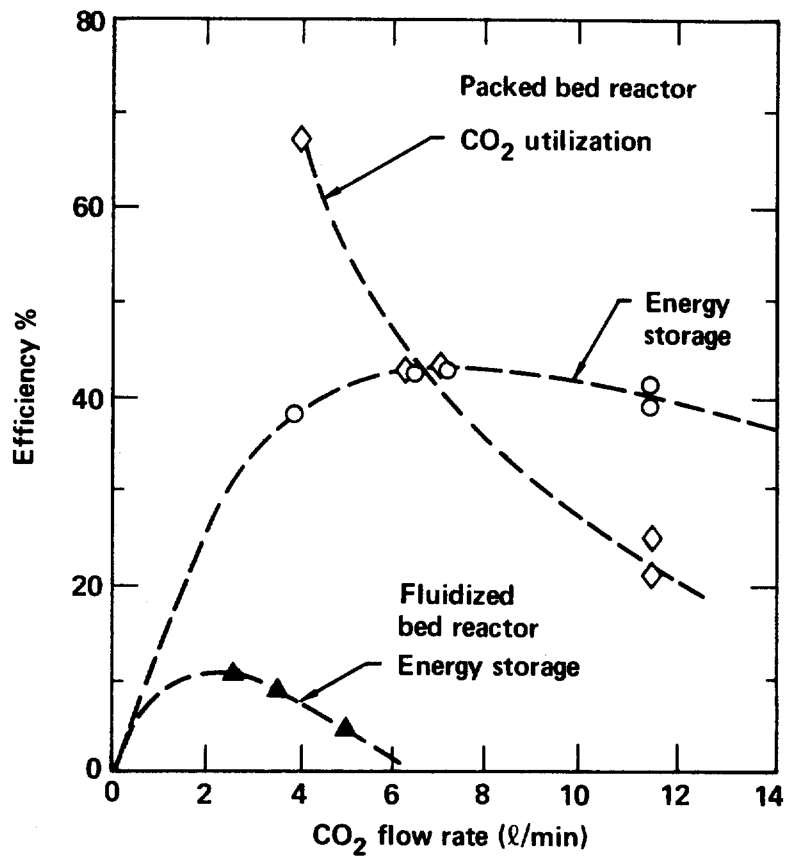
2. Traité de Chimie Industreille, Tome II, Paul Baud, Masson and Cie, Paris (1951).

Figure 1



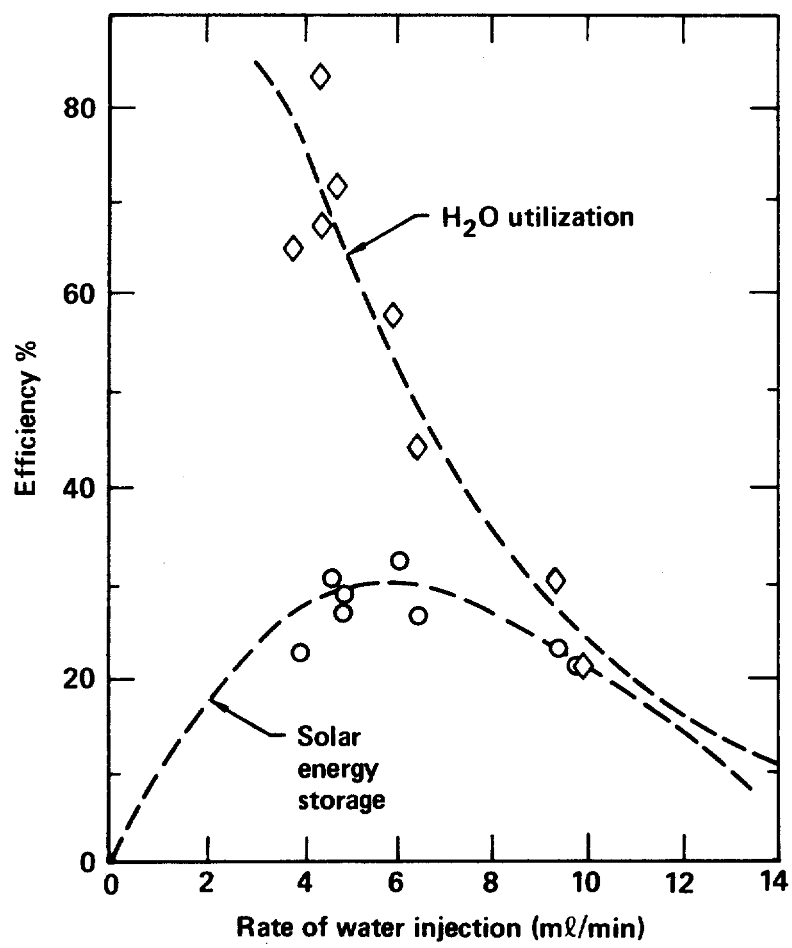
Reactor used for solar gasification. As the packed bed was consumed it was pushed toward the focal plane.

Figure 2a



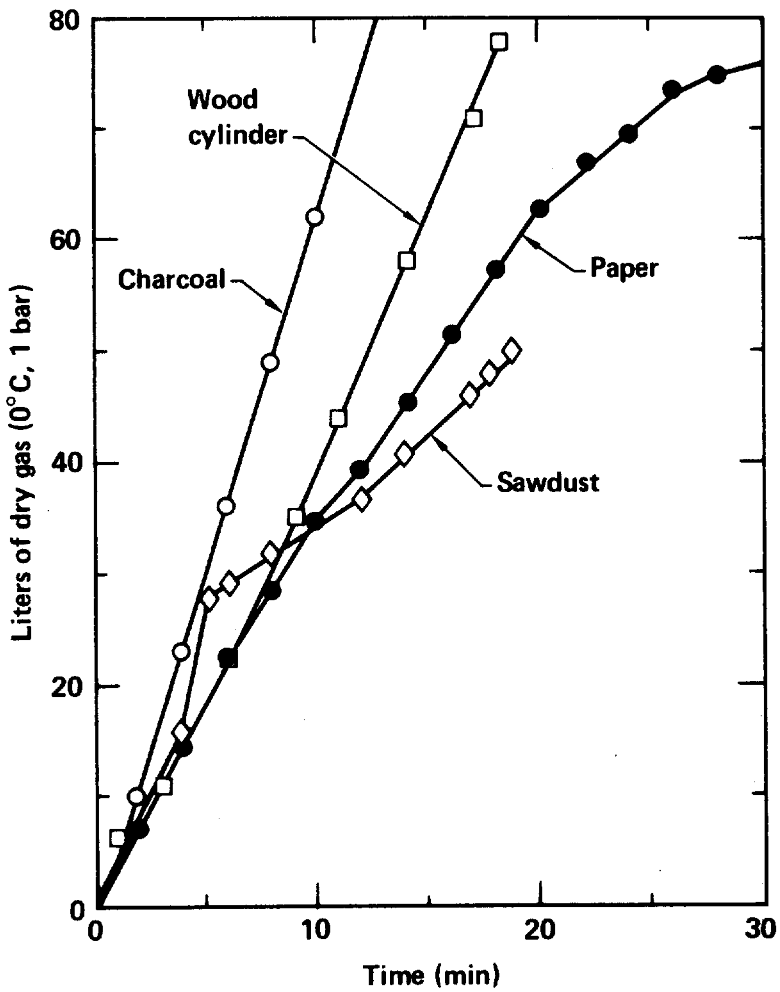
Efficiency of solar energy storage when gasifying charcoal with CO_2 (Fig. 2a) and with H_2O (Fig. 2b). Fig. 2a also shows reduced efficiency measured with fluidized-bed reactor.

Figure 2b



Efficiency of solar energy storage when gasifying charcoal with CO_2 (Fig. 2a) and with H_2O (Fig. 2b). Fig. 2a also shows reduced efficiency measured with fluidized-bed reactor.

Figure 3



Amount and rate of gas production for several fuels. Solar power ~1.2 kW; water injection rate ~4.5 mℓ/min.